NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 12-90

HYPERCAPNIA DURING DEEP AIR AND MIXED GAS DIVING

LCDR JOHN A. STERBA, MC, USNR

MAY 1990

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Elevated carbon dioxide (CO_2) levels in the blood, hypercapnia, can limit work capacity and diver safety. The risk of hypercapnia was determined in six U.S. Navy divers with underwater bicycle ergometery at 190 feet of sea water (FSW) breathing air, plus 300 and 1,000 FSW breathing helium-oxygen using a helmet (oro-nasal mask/demand regulator). Peak-to-peak mouth pressure (Delta P) and breath-to-breath end-tidal partial pressure of CO_2 ($P_{ET}CO_2$) were measured during sixth min of exercise (total work = 193 watts). $P_{ET}CO_2$ values were (mean ± SE) : 63.7 ± 0.4 mm Hg (190 FSW), 52.8 ± 0.3 mm Hg (300 FSW), 54.8 ± 2.0 mm Hg (1,000 FSW). Two divers aborted exercise at $P_{ET}CO_2$ levels (mean ± SD) of 74.0 ± 3.1 and 78.0 ± 2.1 mm Hg, requiring emergency recovery due to severe CO_2 narcosis. Above $P_{ET}CO_2$ of 65 mm Hg (n = 9 dives), symptoms were dizziness and headache and above $P_{ET}CO_2$ of 70 mm Hg (n = 4 dives), severe confusion and amnesia. Delta P did not predict elevated $P_{ET}CO_2$ (r = 0.56). We conclude that $P_{ET}CO_2$ of 70 mm Hg is a safe exposure

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limit for monitored diving, and a termination criteria to evaluate underwater breathing apparatuses.

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I. INTRODUCTION

Elevated carbon dioxide (CO_2) levels in the blood, hypercapnia, is a well recognized risk during deep diving involving heavy work (1). Symptoms of hypercapnia may range from a headache or mild dizziness to confusion which can limit work capacity and compromise diver safety. In order to determine the risk of hypercapnia during deep air and mixed gas diving, the end-tidal partial pressure of carbon dioxide ($P_{ET}CO_2$) was measured in six U.S. Navy divers during a standard underwater exercise stress test at the Navy Experimental Diving Unit (NEDU), Panama City, FL. We assumed that in these six healthy subjects, end-tidal gas sampled alveolar air and the partial pressure of CO_2 in alveolar air (P_ACO_2) equalled arterial PCO_2 (P_aCO_2). Using a dry helmet with an oro-nasal mask and a demand regulator, air was breathed at 190 feet of sea water (FSW), equalling 57.9 meters of sea water (MSW) and helium-oxygen mixed gas was breathed at 300 and 1,000 FSW (91.4 MSW, 304.8 MSW). Underwater exercise was done varying helmet static pressure to determine: (a) maximum tolerated hypercapnia as measured by $P_{ET}CO_2$, and (b) if there is any predictive correlation between peak-to-peak mouth pressure (ΔP), which may reflect UBA breathing resistance, and $P_{ET}CO_2$. The purpose of this study was to define the safe exposure limits of $P_{ET}CO_2$ and ΔP for the physiological evaluation of underwater breathing apparatuses (UBAs).

II. METHODS

A. SUBJECTS

Following a medical history and diving physical exam, a group of six healthy U.S. Navy divers volunteered as experimental subjects for dives to 190 FSW and a separate group of six divers for dives to 300 and 1,000 FSW. All subjects were nonsmokers and were well conditioned with routine physical training and underwater bicycle pedaling for six weeks prior to experimental dives. Caffeine consumption was limited and could not be excluded in these two groups of subjects. Alcohol consumption was limited and not allowed 48 hr prior to diving. Anthropometric data (mean ± SD) for subjects on the 190 FSW dives were: age, 24.5 ± 4.1 yr; weight, 79.2 ± 3.9 kg; and height, 179.4 ± 6.0 cm, and for the 300 and 1,000 FSW dives: age, 26.0 ± 3.0 yr; weight, 80.1 ± 5.1 kg; and height 180.2 ± 3.4 cm.

B. DIVING EQUIPMENT

For the 190 FSW air dives, the dry helmet used was the Superlite 17 (Diving Systems International (DSI), Santa Barbara, CA) also called SL-17 MOD 1 or MK 21 MOD 1 by the U.S. Navy. The SL-17 MOD 1 helmet has an oro-nasal mask and demand regulator (Navy 350, DSI). Both 1/2 in (1.3 cm) and 3/8 in (0.9 cm) internal diameter umbilicals, each 600 ft (182.9 m) long, were used with an over-bottom supply pressure of air at 135 pound per square inch gauge (psig). At 300 FSW, the same SL-17 MOD 1 was used with helium-oxygen (HeO_2) mixed gas. The over-bottom supply pressure through a 1/2 in, 600 foot umbilical was 135 psig. All 600 ft umbilicals were made from 100 ft sections joined by standard U.S. Navy couplings (2). At 1,000 FSW, the same helmet adapted with a regulator for deep HeO_2 diving was used (Gas Services Offshore, Ltd., model Ultraflow 500, Aberdeen, Scotland). This saturation diving helmet, called the

SL-17 MOD 0 or MK-21 MOD 0 by the U.S. Navy, uses a 1/2 in, 100 ft (30.5 m) umbilical supplied with HeO_2 at an over-bottom pressure of 205 psig. A Kinergetics breathing gas heater (model 3375-2, DSI) was used only with the SL-17 MOD 0 at 1,000 FSW. At both 300 and 1,000 FSW for both SL-17 MOD 1 and SL-17 MOD 0, respectively, the helium reclaiming device was not used, according to U.S. Navy diving procedures. The helium reclaiming device is believed to increase exhalation resistance and decrease regulator performance which may increase hypercapnia during heavy exercise.

The regulators used in these dives were new and tuned daily to operating specifications by U.S. Navy divers specially trained to maintain optimal regulator performance. The subjects did not purge their regulators nor was the steady flow valve opened to allow free-flow of gas in the helmet during these studies since both maneuvers increase helmet gas flow and static pressure.

Subjects were dressed in hot water non-return valve (NRV) diving suits supplied with 110°F (43.3°C) water for dives in 35°F (1.7°C) water. All dives were underwater to simulated depths of 190, 300, and 1,000 FSW in a hyperbaric chamber at the Ocean Simulation Facility (OSF), NEDU, Panama City, FL.

C. EXPERIMENTAL DESIGN

In Figure 1, the experimental design is illustrated showing the standardized graded exercise stress test used at NEDU to physiologically evaluate diver performance with various UBAs using underwater bicycle ergometry (Collins, model pedalmate, Braintree, MA). With the diver leaning forward 45° from erect, exercise stress testing was conducted at indicated work levels of 50, 100, and 150 watts for 6-min periods, separated by 4-min period rest intervals. Approximately 43 watts of extra work is required to overcome the combined resistance of wearing a hot water diving suit and pedaling underwater (3). The indicated work level plus actual work level in parentheses including the 43 watts are both shown in Figure 1. The physiological effect of varying helmet static pressure was determined at all three depths by measuring $P_{ET}CO_2$, ΔP, respiratory rate (RR), and subjectively by a dyspnea score. The helmet position was either face forward (FF), or to increase helmet static pressure, face down (FD). The subject maintained the FF or FD position by visualizing an inclinometer mounted on the front of the helmet. Underwater closed circuit monitoring verified the correct body and helmet position. The physiological effect of varying umbilical internal diameter for two standard umbilicals used by the U.S. Navy (3/8 in vs. 1/2 in) was determined only at 190 FSW.

After completing the exercise stress test, divers continued pedaling a 0 watts (free-wheeling) for one min. This allowed the diver to maintain an elevated respiratory rate following exercise to quickly reduce very high levels of $P_{ET}CO_2$ during the recovery phase.

D. PHYSIOLOGICAL VARIABLES

Based on the measured fraction of end-tidal CO_2 ($F_{ET}CO_2$) and the diver's depth, the surface equivalent value of $P_{ET}CO_2$ was measured in units of mm Hg. Breath-to-breath measurements of $P_{ET}CO_2$ were made 1 cm from the diver's lips in the oro-nasal mask with a capillary sample tube. At 190 FSW, the capillary

tube (Polymer Corp., model Nylaflow, Reading, PA) had an internal diameter of 0.078 in (0.198 cm) and at 300 and 1,000 FSW, the sample tube (Penn Tube, model Lee, Mickleton, NJ) had an internal diameter of 0.032 in (0.081 cm). Sample flow was controlled at the helmet by a needle reducing valve (Nupro, model SS-SS2, Willoughby, OH). The sample tube was uninterrupted from the reducing valve placed on the helmet, through the hyperbaric chamber wall to a T-block connection where gas analysis was sampled at 62 ml/min by a mass spectrometer (Perkin Elmer (Marquette Gas Analysis), model MGA 1100, St. Louis, MO). The minimum sample tube length was 34 m (110 ft) with the mass spectrometer as close as possible to the wet pot of the hyperbaric chamber.

As reported elsewhere, the response time to 90% of full scale deflection using an injection of a calibration gas with this end-tidal monitoring system was optimized to 240 msec at 1,000 FSW, 273 msec at 380 FSW, and 290 msec at 190 FSW (4-6). The response time for the mass spectrometer is reported to be 100 msec by the manufacturer and measured in this study to be 109 msec (4-6).

Mouth pressure (P_m) was measured in the oro-nasal mask with a catheter passing through the helmet faceplate to a waterproofed pressure transducer (Validyne Engineering Corporation, model DP-9, 0.5 psi diaphragm, Northridge, CA) attached to the helmet. The range of linear response with this pressure transducer is $\pm$ 35 cm H_2O with a degree of accuracy of $\pm$ 0.4 cm H_2O. The pressure transducer was referenced to ambient water pressure using a finger cot balloon mounted on the diver's suprasternal notch (SSN) (7). The static helmet P_m (P_m-static) was determined during a five sec breath-hold (BH) prior to each exercise level. The absolute difference between inspiratory and expiratory P_m, called peak-to-peak pressure (ΔP) was measured for every breath in the last min of exercise at 150 watts. Respiratory rate was also determined from Pm recordings for the last min of exercise at 150 watts.

The degree of breathlessness, dyspnea, was subjectively evaluated using a score of 0 to 3 for none, mild, moderate, and severe dyspnea, respectively. This scoring system was based on an earlier reported scale of 0 to 2 for none, moderate, and severe dyspnea that was used after the completion of exercise (7). In our study, both inhalation and exhalation dyspnea were evaluated 10 secs before the completion of the six min of exercise to include all proprioceptive and psychological input to dyspnea. Mild dyspnea was defined during training with the subjects as a sensation of wanting more gas, but it would not interfere with performing the exercise. Moderate dyspnea was a very uncomfortable sensation of wanting more gas, and exercise could continue for only a few minutes more. Severe dyspnea was extreme breathlessness, and the subject planned to terminate the exercise momentarily. Prior to diving, subjects were trained to identify the levels of dyspnea during repeated training sessions with a BH after exhaling to residual volume. A score of 1 (mild) was at 5 sec of BH, 2 (moderate) at 10 sec, and 3 (severe) at the BH breaking point, usually at 15-20 sec. This 0 to 3 scoring system was used during underwater exercise to first subjectively rate inhalation then exhalation dyspnea. The "O.K." sign with the hand indicated 0 dyspnea, with 1, 2, and 3 fingers for mild, moderate and severe dyspnea, respectively. Divers were instructed to report a dyspnea score of 3 (severe) for either inhalation or exhalation at any time during the exercise stress test.

E. DATA ANALYSIS

The mean ± SD was determined for $P_{ET}CO_2$, ΔP, RR, and inhalation/exhalation dyspnea scores for all six subjects during the last min of exercise at 150 watts at 190, 300, and 1,000 FSW. The effect of helmet position on static mouth pressure was measured before each work level and averaged. In the absence of any significant differences between the two helmet positions or two umbilical diameters at each depth, the mean ± SE for $P_{ET}CO_2$, ΔP, and RR were then calculated.

All divers completed the exercise stress test except for two subjects at 190 FSW who prematurely terminated 150 watts of exercise. The last 60 sec of data was used to calculated $P_{ET}CO_2$, ΔP, and RR in these two subjects. The dyspnea scores were estimated during an interview with these two subjects after the aborted stress test.

All divers were interviewed by a Diving Medical Officer immediately after completion of the 150 watts of exercise to determine changes in mental status, including short term memory and judgement. Divers were asked if they had any problems or complaints without suggestion of the typical symptoms of hypercapnia (e.g. light-headedness, dizziness, confusion, headache). All symptoms and comments were recorded.

Although the 0 to 3 dyspnea score is ordinal data and has not been proven to have a normal distribution, mean along with ± SD will be reported to illustrate the wide variation in this very subjective determination of dyspnea.

At each depth, a paired Student's t-test was used to determine any difference between FF and FD helmet position on $P_{ET}CO_2$, ΔP, RR, and inhalation/exhalation dyspnea. Likewise, at 190 FSW, any difference between 3/8 in and 1/2 in umbilical diameter was determined for the same physiological variables. A Pearson correlation coefficient was calculated between ΔP and $P_{ET}CO_2$ for each depth and all three depths, collectively. For all statistical evaluations, significance was accepted at $p < 0.05$.

III. RESULTS

A total of 42 dives were completed at 190, 300, and 1,000 FSW. The only divers failing the exercise stress test were two divers who on separate experimental dives, stopped pedaling during the 150 watt work cycle at 190 FSW. Diver #1 terminated at 5 min, 10 sec in the face forward position (1/2 in umbilical) and diver #2 at 4 min and 13 sec in the face down position (3/8 in umbilical). The $P_{ET}CO_2$ for diver #1 averaged 74.0 ± 3.1(SD) mm Hg and diver #2, 78.0 ± 2.4(SD) mm Hg for the last min of exercise. Immediately prior to termination, both diver's respiratory rate, ΔP, and pedaling rate were consistent and the divers did not indicate any problem via their open-microphone in the helmet. The signs attributed to hypercapnia during diver recovery when $P_{ET}CO_2$ in both divers dropped slightly (70 - 72 mm Hg) included agitation, confusion, and the inability to swim to the ladder or adjust diving gear. Both divers required complete assistance by the safety diver underwater and were hoisted from the water. Within two min of aborting the dive with the helmet removed, each subject was slow to correctly respond to

questions evaluating orientation to person, place, time, and situation. They gave incorrect answers to questions assessing short-term memory plus judgement was impaired. It was determined that both divers were amnestic to stopping underwater pedaling and failing to respond to commands. Each diver developed a headache within minutes of terminating the dive, which was relieved with breathing hyperbaric oxygen during standard air decompression. During decompression, each diver was alert, responded appropriately to all questions, yet complained of fatigue which lasted the remainder of the day. Following decompression, neurological evaluation was normal for both divers.

For all three depths of 190, 300, and 1,000 FSW, the P_m-static for face down position (0.3 ± 2.7(SE) cm H_2O) was significantly greater than the face forward position (-8.1 ± 0.4(SE) cm H_2O), both using the 1/2 in umbilical ($p < 0.001$). Umbilical diameter did not influence helmet static pressure.

Respiratory rate, shown in Figure 2, was not significantly different for either helmet position or umbilical diameter, averaging 23.5 ± 0.6(SE) breaths/min at all three depths at 150 watts (n = 42). There were no differences in peak-to-peak pressure (ΔP) between helmet positions at any depth, or between umbilical diameters at 190 FSW, illustrated in Figure 3. The average ΔP was 21.0 ± 1.3(SE) cm H_2O at 190 FSW, 18.7 ± 2.5(SE) cm H_2O at 300 FSW, and 13.8 ± 0.3(SE) cm H_2O at 1,000 FSW.

The $P_{ET}CO_2$ is illustrated in Figure 4 for 190, 300, and 1,000 FSW. Helmet position and umbilical diameter did not significantly affect $P_{ET}CO_2$ at 190 FSW. Likewise, at either 300 or 1,000 FSW, helmet position did not significantly affect $P_{ET}CO_2$. The average $P_{ET}CO_2$ was 63.7 ± 0.4(SE) mm Hg at 190 FSW, 52.8 ± 0.3(SE) mm Hg at 300 FSW, and 54.8 ± 2.0(SE) mm Hg at 1,000 FSW.

The graph of $P_{ET}CO_2$ vs. ΔP from all depths shown in Figure 5 is only weakly correlated ($r = 0.56$, $p < 0.001$). For each depth, the correlation coefficients were, $r = 0.34$ (NS) for 190 FSW, $r = 0.67$ ($p < 0.01$) for 300 FSW, and $r = -0.42$ (NS) for 1,000 FSW.

Inhalation and exhalation dyspnea scores are shown in Figures 6 and 7 for all depths. Helmet attitude and umbilical diameter did not influence either inhalation or exhalation dyspnea scores.

Summarizing the subjective evaluation of hypercapnia, inability to think clearly during the exercise and subsequent mild headache were common complaints above a $P_{ET}CO_2$ of 65 mm Hg (8 dives at 190 FSW and 1 dive at 300 FSW). For the four dives with $P_{ET}CO_2$ above 70 mm Hg, two divers were amnestic as mentioned above and the other two divers complained of severe confusion, and not feeling well at the termination of exercise. Confusion and dysphoria lasted a few min after the helmet was removed. Symptoms of headache and fatigue throughout the remainder of the day were common following dives having $P_{ET}CO_2$ above 70 mm Hg.

IV. DISCUSSION

The mean $P_{ET}CO_2$ in this study ranged from 53 to 64 mm Hg during underwater exercise stress testing at 190, 300, and 1,000 FSW. These values are in close agreement with previously published values of $P_{ET}CO_2$ during exercise performed

under pressure (1,7-17). Individual values of $P_{ET}CO_2$ have been reported 70 mm Hg and higher (1,8-10,18). Recently in a brief report, $P_{ET}CO_2$ was monitored in one subject challenged with resistance breathing during underwater exercise at 190 FSW (19). The subject had a $P_{ET}CO_2$ of 76 mm Hg 20 sec before refusing to terminate the exercise. This resulted in emergency recovery from the water with loss of consciousness for 70 sec (19). As reported earlier from our study (20), the highest mean values of $P_{ET}CO_2$ were 74 and 78 mm Hg in two divers during underwater exercise at 190 FSW. These divers prematurely stopped pedaling (150 watts indicated or 193 watts actual work) without any warning from monitoring the open-microphone, or observing any variations in $P_{ET}CO_2$, ΔP, respiratory rate, or pedaling frequency. Dyspnea scores for both divers were 2 (moderate) for inhalation and 1 (mild) for exhalation. Both divers were amnestic to the emergency recovery which required a safety diver due to severe CO_2 narcosis causing purposeless movements, confusion, combative behavior, and inability of the divers to follow commands. Examination by the Diving Medical Officer revealed impaired short-term memory and judgement which lasted a few min after the helmet was removed.

Overall, four of 42 dives had mean values of $P_{ET}CO_2$ during the last min of exercise at or above 70 mm Hg ranging in symptoms of mild confusion and subsequent headaches to the two episodes of extreme narcosis described above. We conclude that with this degree of hypercapnia, there is an unacceptable risk of severe CO_2 narcosis at or above a $P_{ET}CO_2$ of 70 mm Hg during underwater exercise. This safe exposure limit of a $P_{ET}CO_2$ of 70 mm Hg is now used as a termination criteria for the physiological evaluation of underwater breathing apparatuses during exercise stress testing at NEDU.

At NEDU, the peak-to-peak mouth pressure, ΔP, is measured during the unmanned engineering evaluation of UBAs with limits established to help exclude those UBAs with inherently high breathing resistance (21). If ΔP was closely correlated with hypercapnia, maximum limits of ΔP corresponding to a $P_{ET}CO_2$ of 70 mm Hg could be established to determine which UBAs were acceptable for safe diving operations. In this study, ΔP was weakly correlated with $P_{ET}CO_2$ and should not be used alone to accept or reject a particular UBA undergoing an unmanned engineering evaluation on a breathing machine.

The small increase in helmet static pressure from FF (-8.1 cm H_2O) to FD (0.3 cm H_2O) helmet position did not affect any of the physiological variables measured to assess pulmonary function: $P_{ET}CO_2$, ΔP, RR, inhalation or exhalation dyspnea. This lack of effect is in agreement with no significant effect reported for static lung loads of -10 to 0 cm H_2O on $P_{ET}CO_2$, RR, and dyspnea in three subjects exercising supine (197 watts) at 190 FSW (7).

The long recognized anesthetic property of CO_2 (22) may explain why divers in this study reported only mild to moderate dyspnea scores during the exercise stress test. Divers commented that 150 watts not only exceeded heavy work performed in the open ocean, it would not be safe to sustain this high level of work due to what divers term as, "over-breathing the rig". The inhalation and exhalation dyspnea scores are not reliable indicators of respiratory stress with such large variation and not being able to predict two episodes of severe CO_2 narcosis in this study.

Physiologically, there have been many studies investigating hypoventilation resulting in hypercapnia during diving which have been comprehensively reviewed by Lanphier and Camporesi (1). The reasons for CO_2 retention include: high partial pressure of inspired oxygen decreasing respiratory drive, elevated work of breathing with increased gas density plus the hydrostatic effect of immersion, inadequate respiratory response to exertion, years of diving experience, and extensive breath-hold diving experience with decreased CO_2 sensitivity (1).

Hypercapnia differs from the term "carbon dioxide retention", first proposed by Lanphier in 1955 (8), which applies to those individuals capable of eliminating CO_2 in a normal manner but for some reason failing to do so. The CO_2 rebreathing technique of Read (23) and the method to measure inspiratory pressure at 0.1 sec into inhalation ($P_{0.1}$) of Whitelaw, et al (24) have not determined any difference between divers and non-divers for CO_2 retention (25) or between divers suspected of being CO_2 retainers during tethered swimming (26). Despite a lack of evidence proving a significant difference between one population of divers as CO_2 retainers and another population as non-CO_2 retainers (1), the physiological mechanism(s) of severe hypercapnia developing in healthy divers without the strong sensation of dyspnea requires further investigation.

V. CONCLUSION

The inadequate respiratory drive during underwater exercise stress testing at NEDU resulting in severe hypercapnia cannot be predicted by ΔP, or monitoring subjective determination of dyspnea. We conclude that the $P_{ET}CO_2$ of 70 mm Hg should be a termination criteria for the physiological evaluation of UBAs and also be a safe exposure limit for monitored underwater exercise to avoid severe CO_2 narcosis.

VI. RECOMMENDATIONS

The SL-17 MOD 1 and MOD 0 support heavy underwater exercise, with no significant physiological differences in diver performance for either 1/2 in or 3/8 in umbilical diameter or helmet position. Both helmets are recommended for fleet use.

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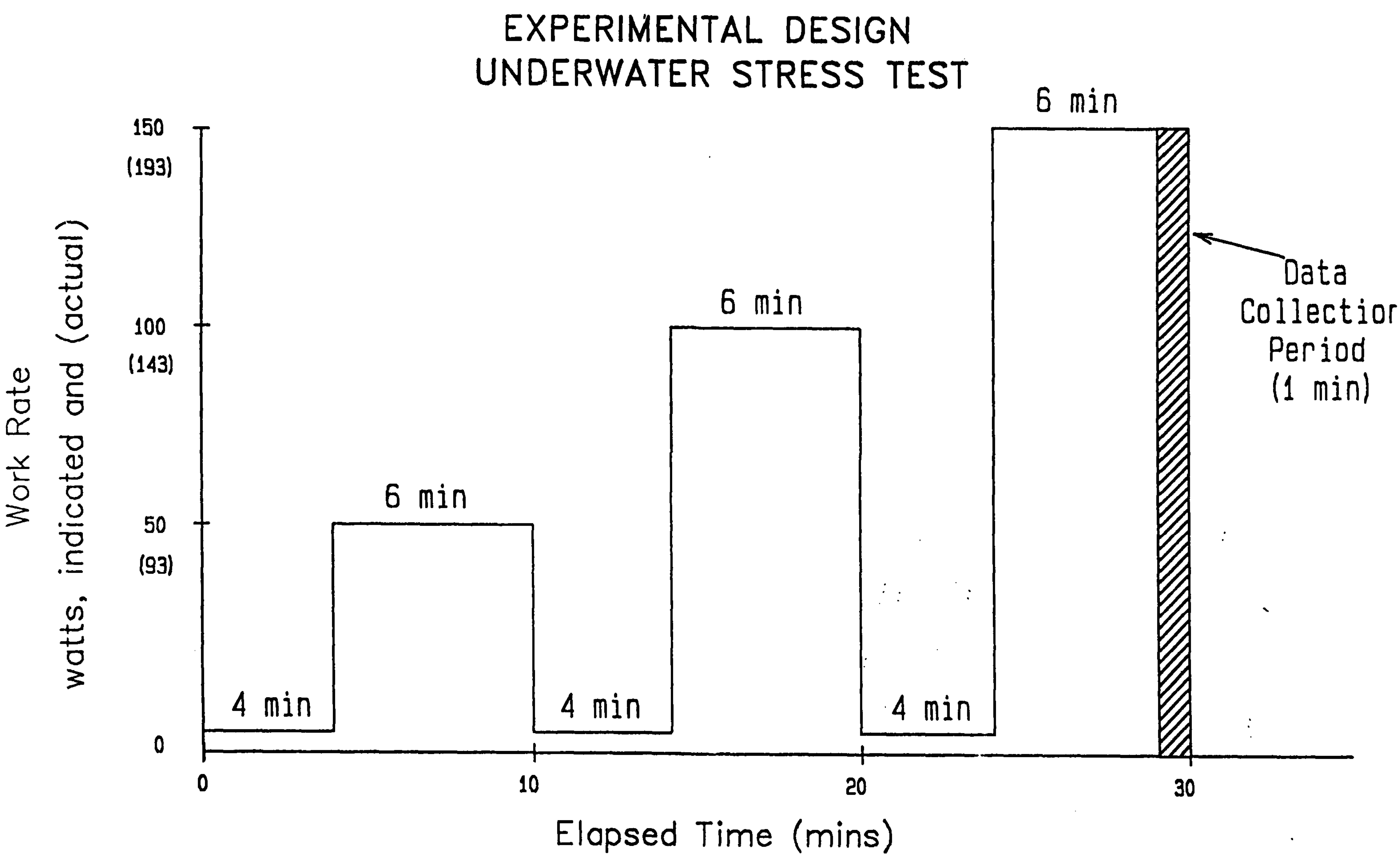
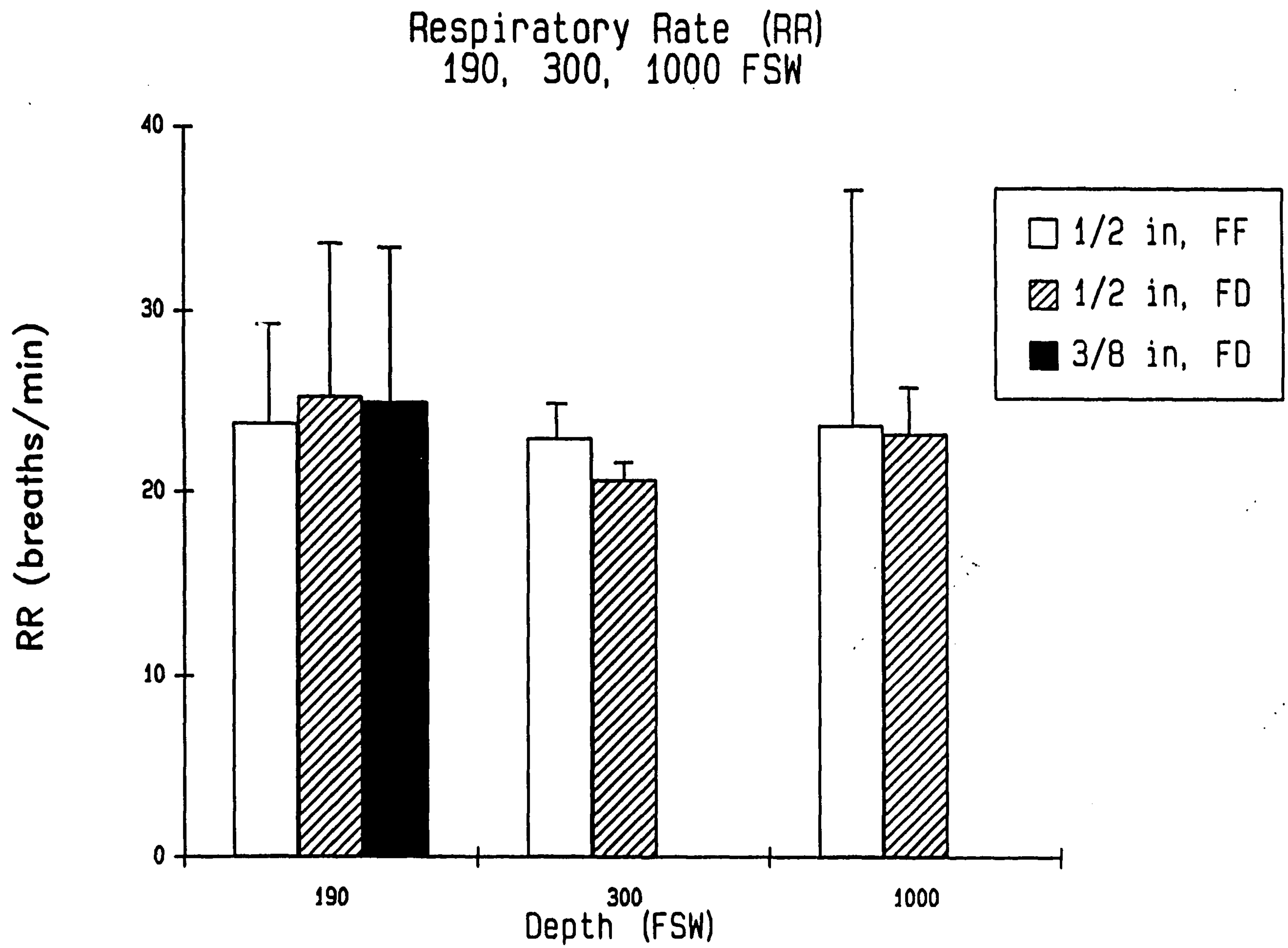


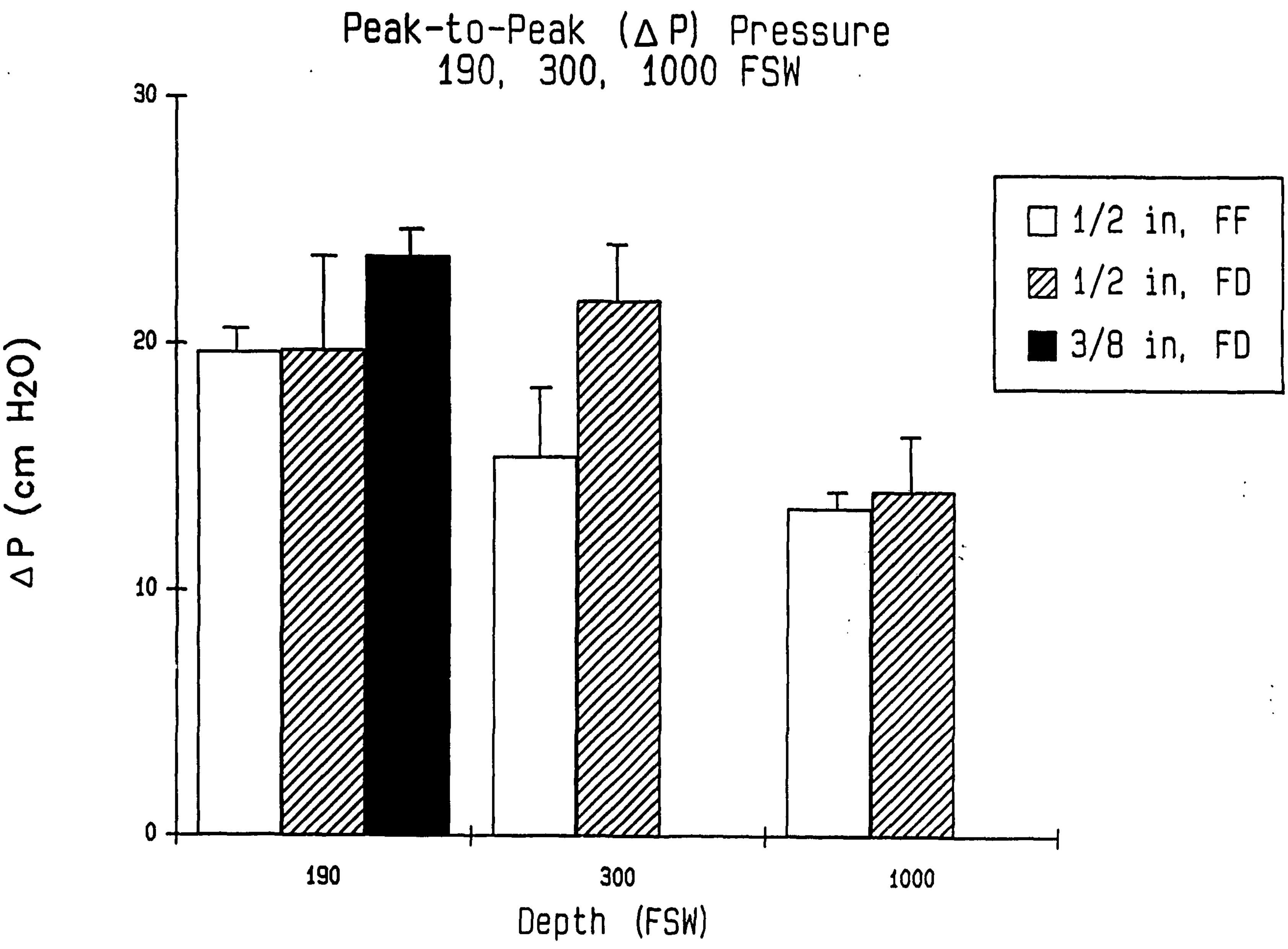
EXPERIMENTAL DESIGN
UNDERWATER STRESS TEST
Work Rate
watts, indicated and (actual)
150
(193)
100
(143)
50
(93)
0
4 min
6 min
4 min
6 min
4 min
6 min
Data
Collectior
Period
(1 min)
0
10
20
30
Elapsed Time (mins)

FIGURE 1.



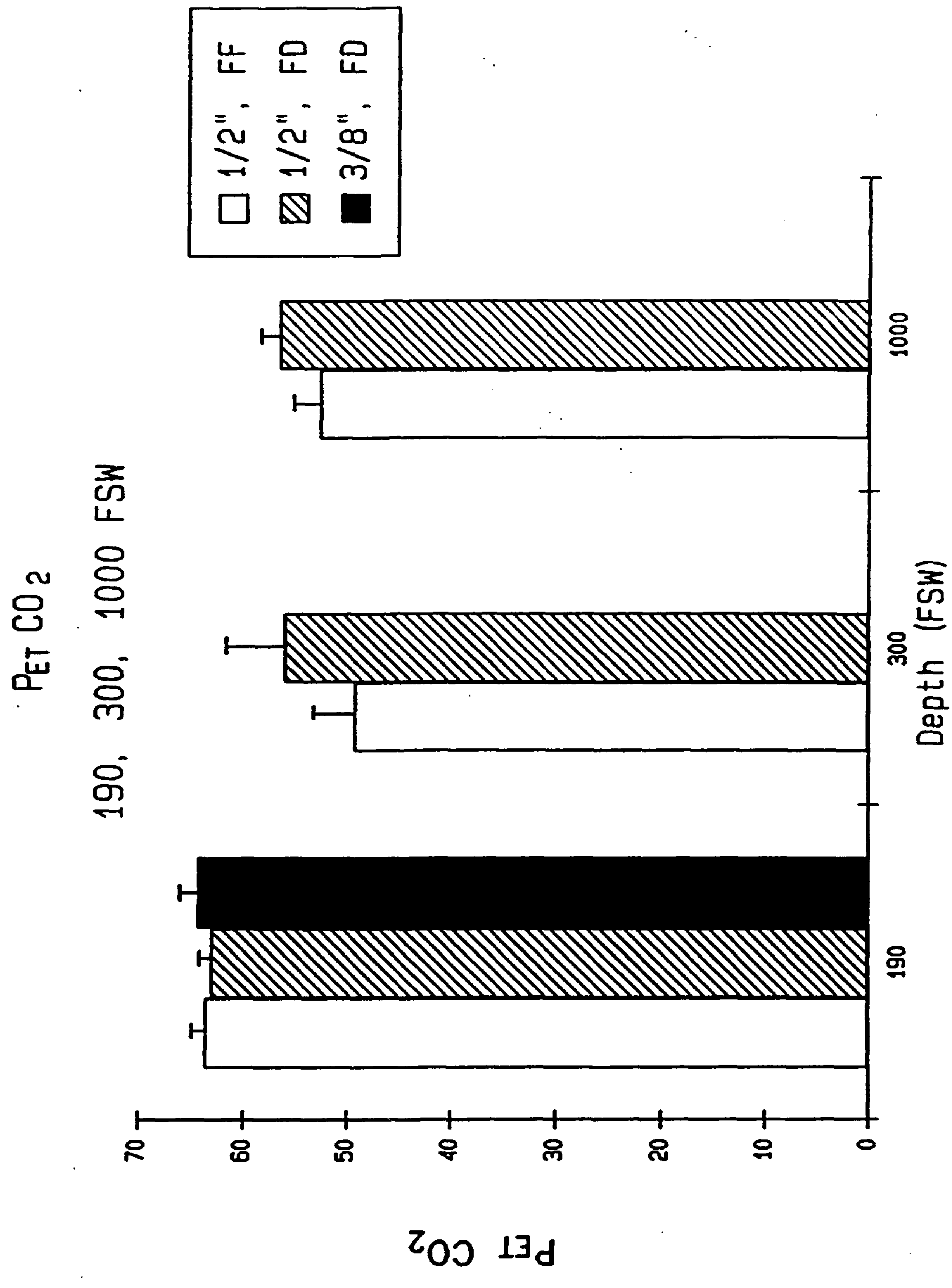
Respiratory Rate (RR)
190, 300, 1000 FSW
RR (breaths/min)
40
30
20
10
0
190
300
1000
Depth (FSW)
1/2 in, FF
1/2 in, FD
3/8 in, FD

FIGURE 2.



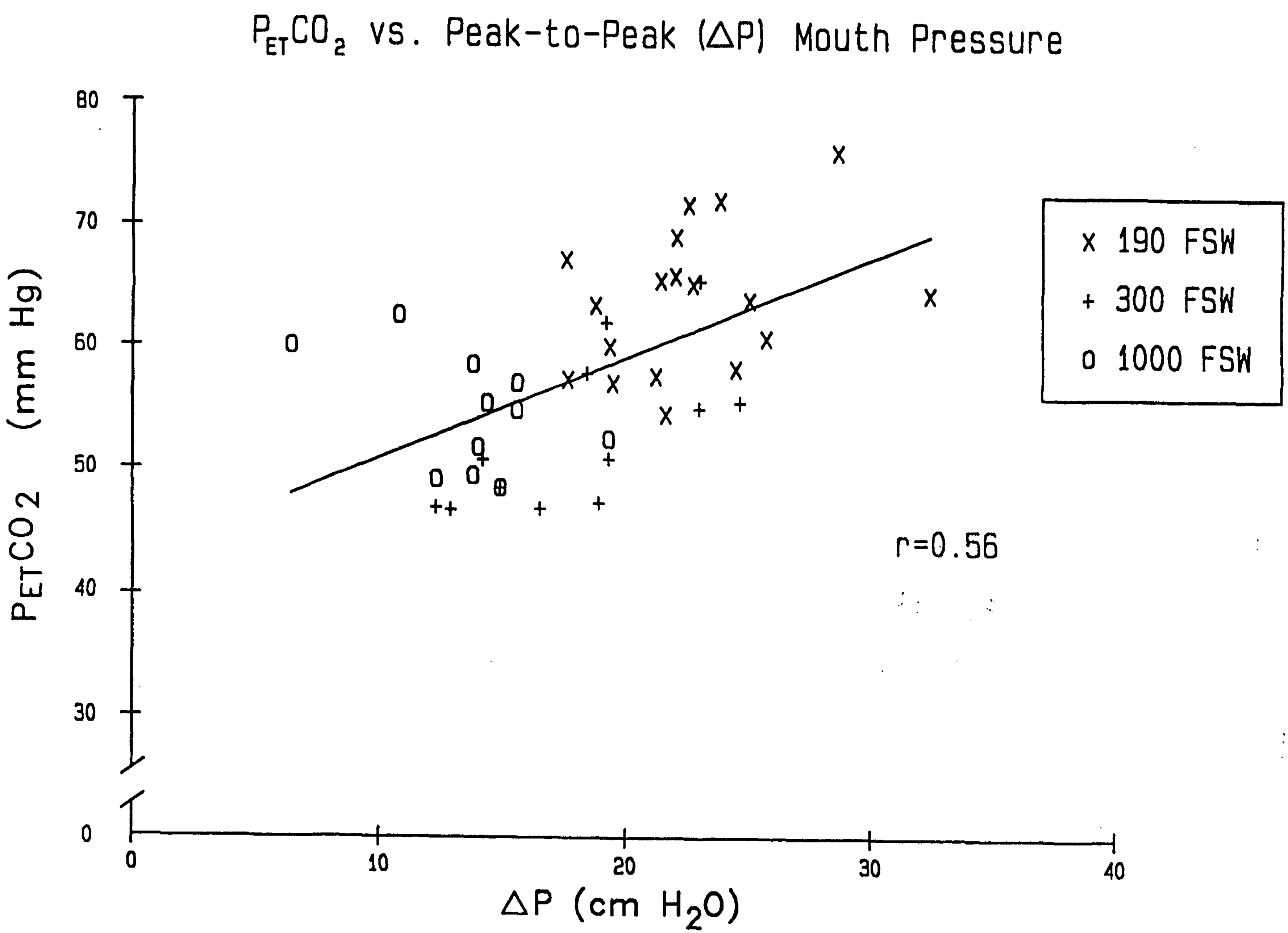
Peak-to-Peak (ΔP) Pressure
190, 300, 1000 FSW
30
20
10
0
ΔP (cm H2O)
1/2 in, FF
1/2 in, FD
3/8 in, FD
190
300
1000
Depth (FSW)

FIGURE 3.



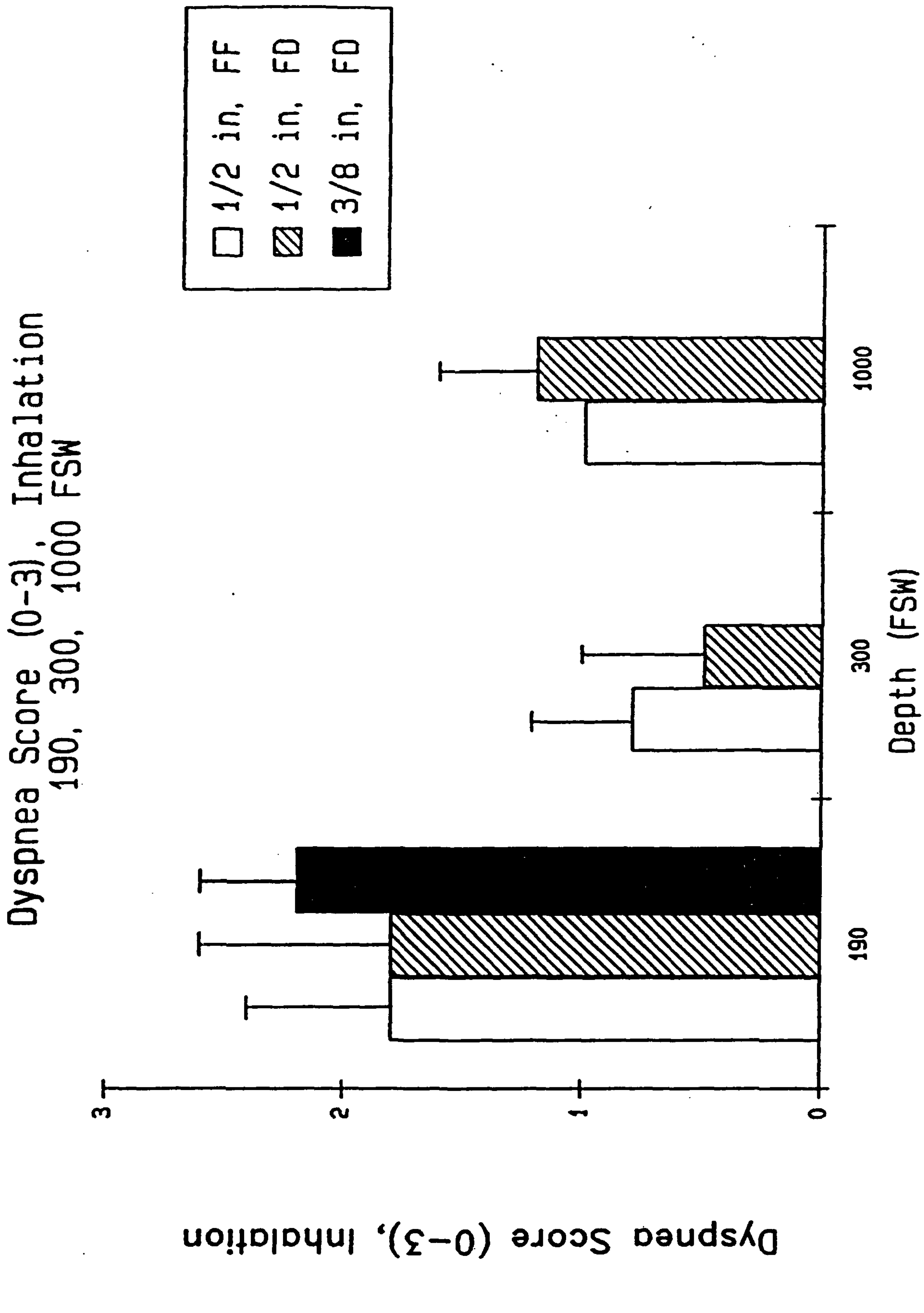
P_{ET} CO_2
190, 300, 1000 FSW
1/2", FF
1/2", FD
3/8", FD
P_{ET} CO_2
70
60
50
40
30
20
10
0
190
300
1000
Depth (FSW)

FIGURE 4.



$P_{ET}CO_2$ vs. Peak-to-Peak (ΔP) Mouth Pressure
$P_{ET}CO_2$ (mm Hg)
80
70
60
50
40
30
0
0
10
20
30
40
ΔP (cm H_2O)
x 190 FSW
+ 300 FSW
o 1000 FSW
r=0.56

FIGURE 5.



Dyspnea Score (0-3), Inhalation
190, 300, 1000 FSW
1/2 in, FF
1/2 in, FD
3/8 in, FD
Dyspnea Score (0-3), Inhalation
0
1
2
3
190
300
1000
Depth (FSW)

FIGURE 6.

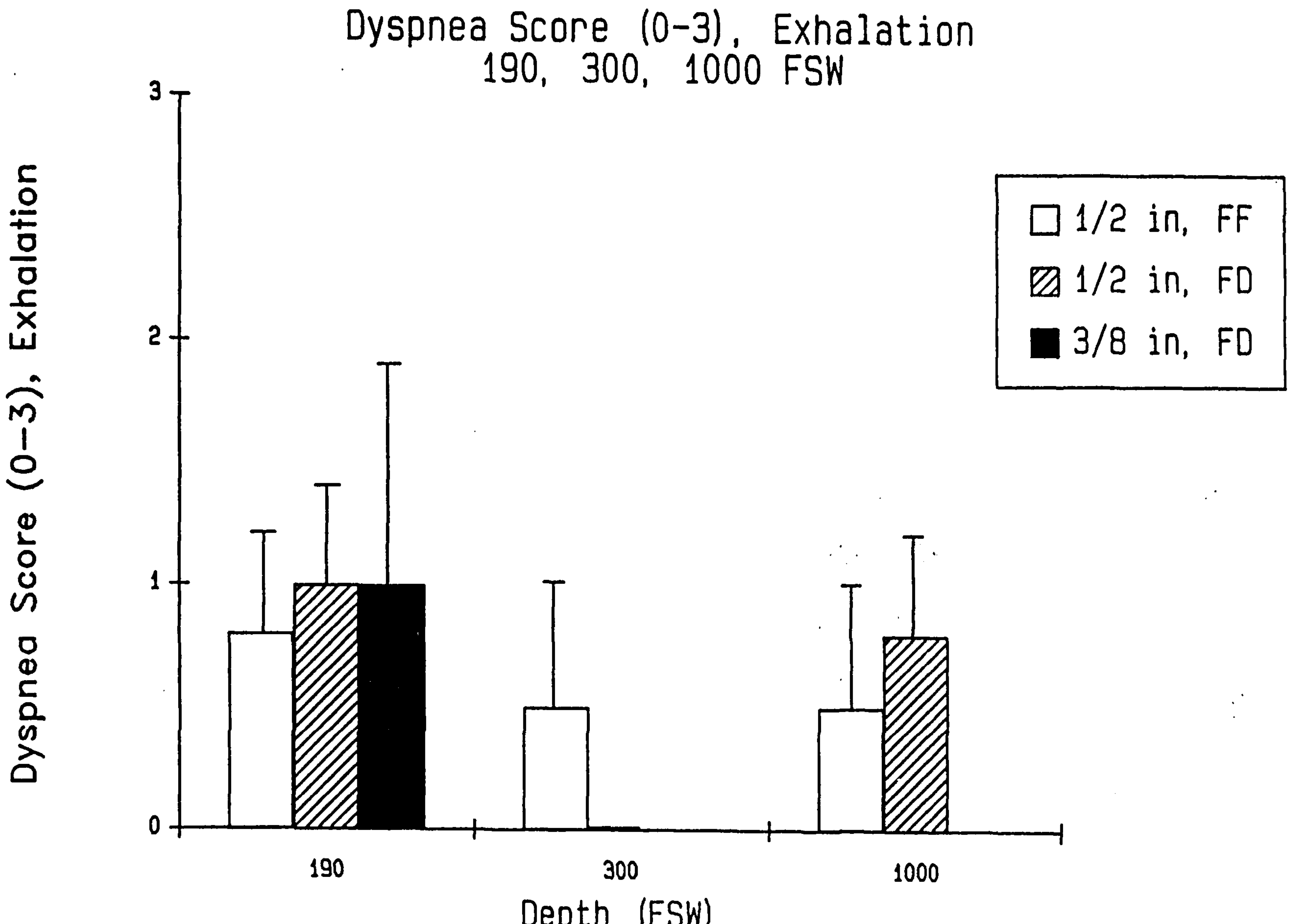

Dyspnea Score (0-3), Exhalation
190, 300, 1000 FSW
Dyspnea Score (0-3), Exhalation
0
1
2
3
190
300
1000
Depth (FSW)
1/2 in, FF
1/2 in, FD
3/8 in, FD

FIGURE 7.